1. Introduction

1.1 BACKGROUND

A nuclear air cleaning system is provided to protect the public and plant operating personnel from airborne radioactive particles and gases which are, or could be, generated or released from operations conducted in a nuclear reactor, fuel fabrication or processing plant, radiochemical operation, laboratory, or other nuclear operation. Such a system is characterized by operation at very high contaminant collection levels, generally orders of magnitude greater than those exhibited by air cleaning systems employed in commercial, industrial, or pollution control applications. The component almost universally included in such systems is the high-efficiency particulate air (HEPA) filter. This type of filter may be supplemented by common air filters, bag filters, cyclones, scrubbers, or other devices used in more conventional applications but is nearly always employed in the nuclear air or gas cleaning system as the final barrier between a contained space (in which radioactive particulates could be generated) and the point of release to the atmosphere (i.e., the stack) or to an environmentally controlled space of the facility.

The prevention of even extremely low concentrations of airborne contamination is fundamental to the safe operation of a nuclear facility.[1] It is also an important factor in the economic operation of such facilities. Although protection of the health and safety of the public and of plant personnel is the primary consideration, the high costs of decontamination and the possibility of shutdown of the facility in the event of an accidental airborne release of radioactive material are also important considerations.

Radioactive substances tend to deposit or "plate out" on ducts, components, and other exposed surfaces and, in time, become sources of persistent ionizing radiation. This deposition can severely complicate maintenance and operation of a facility unless eliminated close to the source. These problems are of particular concern in power reactors and fuel reprocessing facilities because of their potential for releasing large amounts of radioactive material in the event of a system malfunction or upset.

1.2 PURPOSE AND SCOPE

Much of the information pertinent to the design, construction, and testing of very-high-efficiency air and gas cleaning systems for nuclear applications is contained in limited-distribution topical reports, technical papers, and job specifications that are often not readily available to designers. Although there is a growing body of standards relating to the subject, the background information necessary for their effective interpretation is scattered. The purposes of this handbook are to summarize available information in a manner that is useful to the designer, to point out shortcomings in design and construction practice, and to provide guides and recommendations for the design of future systems. The handbook summarizes findings from the literature and air cleaning practices at laboratories, production facilities, power and research reactors, and radiochemical and fuel reprocessing facilities. The judgments and recommendations presented reflect the experience of users and conditions that exist in operating systems where airborne radioactive material is being successfully controlled on a day-to-day basis, often in situations where personnel have had to live with, or adapt to, serious deficiencies in design or construction.

This handbook is limited to the mechanical or hardware phase of design. Functional design—the sizing of a system or selection of components to meet the needs of a specific application—is beyond its scope. The design of ventilation systems, of which the air cleaning systems are a part, is also beyond the scope of the handbook except as the ventilation system design affects the operation and reliability of the air cleaning facilities, or, conversely, as the air cleaning facilities affect the operation and reliability of the ventilation system. The functional design of nuclear air cleaning systems is covered in Safety Monograph No. 17 of the International Atomic Energy Agency (IAEA),[2] in various Regulatory Guides of the Nuclear Regulatory Commission (NRC),[3-5] and in the ERDA Manual.[6] The functional design of ventilating systems is covered in *Industrial Ventilation*,[7] the ASHRAE handbooks,[8] ANSI Z9.2,[9] and numerous textbooks. The handbook does not cover the theories of air filtration or gas adsorption; however, discussions of air filtration theory can be found in White's and Smith's *High Efficiency Air Filtration*[10] and Davies' *Air Filtration*;[11] gas adsorption theory of interest to the nuclear industry is covered best in the proceedings of the biennial AEC (now ERDA) Air Cleaning Conferences.

1.3 DESIGN CONSIDERATIONS

The design of nuclear air cleaning systems is complicated by the extremely high collection efficiencies required to meet the maximum permissible concentration (MPC) values that have been established for radioactive substances in air.[1] In many conventional situations (i.e., commercial, industrial, and air pollution control), dust, chemical fumes, and other contaminants can be detected by the human senses before they reach concentrations that pose a serious immediate threat to health or safety. The situation is quite different in nuclear systems because of the complete insensitivity of man to the presence of radioactivity, even at levels that represent an immediate danger to life, and because of possible long-term effects of exposures even at low levels. The lowest threshold limit values (TLV)[12] specified for most chemical contaminants in air are at least two orders of magnitude higher than the MPC of any radioactive material.

The common air filters used in conventional air cleaning applications are unable to decontaminate air to the levels required to meet these MPCs. Even the best of such filters exhibit number decontamination factors (DF) no greater than 6 to 7 for submicron particles (i.e., those having an aerodynamic diameter of less than 1 μm), and the DF of most filters is 2 or less for particles in this range.[13,14] To meet the requisite MPCs for contaminants present as, or adsorbed on, particulate matter, the HEPA filter must be used. By definition,[15] this type of filter must have a minimum number efficiency[16] of 99.97% for 0.3-μm particles; that is, a number decontamination factor of at least 3333 for all measurable particles, at any concentration, down to at least a 0.3-μm aerodynamic diameter. Similarly, the iodine adsorption units used in nuclear air and gas cleaning service must also exhibit collection (i.e., decontamination) efficiencies substantially greater than adsorption units used in fume and odor control and most toxic or noxious gas control applications. For these components to function at their required performance levels, the manner in which they are installed, the connecting ductwork, and the ancillary components required to complete the air cleaning function must all meet standards of design and installation substantially higher than those which prevail in most nonnuclear situations. That such high standards can be met routinely and on a continuing basis is evidenced by the superlative safety record of most nuclear installations and by the control of releases to the atmosphere even under severe upset conditions.

If airborne radioactive material is released from the system, there is the possibility of seriously contaminating occupied spaces of the plant, as occurred in the St. Laurent fuel meltdown incident in France, or of contaminating the surrounding countryside, as occurred in the Windscale reactor incident in England several years ago. Even a minor incident, in terms of the actual weight or volume of radioactive material released, could shut down a costly facility for an extended period of time. The costs of decontamination can be thousands of times the losses due to such ordinary hazards as fire, explosions, or chemical spills, as illustrated below by the loss experience due to a small glove box accident at an ERDA laboratory.[17]

Casualty loss due to fire	$100
Casualty loss due to explosion	$500
Cost of cleanup and decontamination	$76,200

In addition, the deposition and "plate out" of radioactive particulate matter and gases in and on ductwork, housings (i.e., equipment casings), filters, and other air cleaning system components limits access, obstructs maintenance, and increases the cost of operation. The designer must appreciate these substantial differences between nuclear and conventional air cleaning systems. Concentrations of radiotoxic materials in the air cannot be maintained below statutory limits[1] if the design or layout of the system, or selection or installation of components, is deficient. Some operations in the past have relied to some extent on dilution of airborne radioactive wastes with large volumes of air, followed by dispersal in the atmosphere. This practice is no longer acceptable in view of recent "as low as reasonably achievable" (ALARA) regulations, and heavy emphasis must be placed on positive removal of radioactive particulates, fumes, and gases by means of well-designed and -maintained filtration and adsorption systems.

1.4 SPACE CONSIDERATIONS

The location and space allocations for exhaust and air cleanup systems must receive close attention beginning with the early stages of building planning and layout and continuing through construction of the facility. Failure to provide adequate space for ductwork in early building layouts often results in the inability to achieve good aerodynamic design, in excessive velocity and pressure losses that can compromise system operation, and in dynamic conditions that can cause outleakage of contamination, even in ductwork that operates under negative pressure. Poor location of filter housings, fans, and dampers may limit their accessibility and thereby decrease ability to maintain the system. Also, since filters are collectors of radioactive (or potentially radioactive) dust, they can contain substantially greater concentrations of radioactive material than the air of the contained space served by the system. Changing filters in open attics or crowded spaces of the building increases risks at a time when risk is already higher than normal. Adequate access to and space surrounding housings and filter installations decreases this risk. Space allotted for access to housings and equipment must not be encroached upon for storage, field shops, or other operational conveniences during the life of the facility.

1.5 SYSTEM FLEXIBILITY

A shortcoming often encountered in ventilation and air cleaning system designs is failure to anticipate the possibility of future system modification. Although lack of ventilation system flexibility may create no problems in nuclear reactors and other facilities that have a fixed function, in radiochemical operations and particularly in laboratories and experimental facilities where change is almost standard procedure, provision for future system modification at the time of original system design can pay for itself many times over. The rebuilding of radioactively contaminated ducts and air cleaning systems is costly and hazardous, at best, and can be even more costly and hazardous when some provision for flexibility has not been left in the original design. Because of the radioactivity problem, the costs of modifying or rebuilding a nuclear plant exhaust or air cleanup system may run five to ten times the cost of similar work carried out in a nonradioactive system. Provision for expansion of a system, including extra housing space, reserve fan and motor capacity, additional tie-on points, and sufficient mechanical joints in ductwork to permit reasonably easy dismantling, should be given serious consideration in initial planning.

Temporary systems may not justify the extra capital investment for providing flexibility. Nevertheless, the designer should keep in mind that temporary systems often become permanent or are adapted for other purposes. Short cuts in design that make the modification of even a temporary system difficult can often become very costly to the owner in the long run.

1.6 COORDINATION OF DESIGN AND CONSTRUCTION

The mechanical contractor cannot be expected to supply more than the minimum requirements shown in the drawings and specifications. He cannot be expected to build a system having the special features and requirements of a nuclear air cleaning system unless the design details and specifications clearly define them. It is the functional designer's responsibility to correctly interpret the owner's needs and to develop clear and accurate system criteria. It is the mechanical designer's responsibility, in turn, to interpret these criteria and translate the functional design requirements into detailed equipment and construction drawings and specifications that can be followed by workmen with no experience in this specialty. It is also the mechanical designer's responsibility to ensure that the system, as it will be built, will meet the owner's needs in terms of a safe, effective, reliable, maintainable, and economic system.

An example of poor design and construction coordination occurred in a power reactor containment purge system. The facility designer, when allocating space for ventilation and air cleaning equipment, allowed a nominal 144-in. width for a six-wide bank of 24- by 24-in. HEPA filters. No verification of this dimension was made by the mechanical designer, and the drawings went to the constructor who proceeded to pour concrete. The difficulty that developed is that a six-wide bank of 24- by 24-in. filters should be installed in a housing at least 151 in. wide (and preferably 158 in. wide) to provide room for a reliable filter mounting frame and to provide ease of filter changing. This type of error should have been recognized in the mechanical design stage. To make matters worse, no embedments were provided in the concrete to which the filter mounting frame could be seal-welded. This error resulted in a filter installation that is, at best, questionable.

It is also important for contractual relationships to be carefully defined and enforced. If the constructor is to be responsible for correct performance of the installed system, then test procedures, identification of the parties who will make and evaluate test results, and requirements for remedying errors and deficiencies must all be specified in the contract documents. It is not enough merely to require that the system meet some minimum dioctyl phthalate (DOP) test efficiency (usually 99.95%). If the system is to meet its intended service requirements, technical requirements must be carefully followed during preparation, review, and contractual acceptance of drawings and specifications, as well as during performance of the work in the field.

1.7 COST CONSIDERATIONS

Shortcuts and compromises with good design practice result in unduly high operating costs throughout the life of the system, as well as reduced system reliability and performance. A common error in the planning and design of nuclear air cleaning systems is to place too much emphasis on first (i.e., capital) costs. Minimizing first costs often results in high operating and maintenance costs if desirable optional features are omitted or if sacrifices are made in the amount or quality of space provided for components, equipment, and ductwork. During the life of the system, operating and service costs usually far exceed the first cost of building the system. A survey by the Harvard Air Cleaning Laboratory showed that operation and maintenance accounted for more than 85% of the total cost of owning a nuclear air cleaning system, based on 20-year amortization.[18]

Errors are sometimes made in choosing between alternate methods of accomplishing a desired objective because of the failure to consider all aspects of cost. When estimating capital costs of air cleaning systems, for example, the costs of special filter housings, dampers, fire protection facilities, clothing-change facilities, and other unusual (as compared with conventional air cleaning practice) provisions are often overlooked and may result in substantial avoidable maintenance costs for the sake of a few dollars' savings in first costs. For example, higher efficiency prefilters may greatly extend the life of the downstream HEPA filters and perhaps have longer life themselves, thereby increasing the time between filter changes. This is important because replacement of highly contaminated HEPA filters may cost as much as 50¢ per cfm of installed capacity.[19] Often, when estimating filter replacement costs, only the "do" phase of the operation is considered, with little or no heed given to the "make ready" and "put away" phases; yet these are generally the most time consuming and costly phases of a filter change in a nuclear air cleaning system. The time-consuming activities of clothing change, preinstallation inspections, health physics monitoring, and decontamination of the area and equipment after the change are often overlooked. Other factors overlooked are escalations of labor and materials cost and the ability to extend HEPA filter life by the selection of various combinations of prefilters, bank size, airflow rate, or other system parameters. Appendix B provides a form to assist the designer in estimating capital and operating costs and a form that breaks down a filter (or adsorber) change into at least its major elements.

1.8 PURPOSE OF THE HANDBOOK

The information given in this handbook will supplement the designer's previous knowledge and understanding of ventilation and air cleaning system design and construction by supplying background information on components and requirements for these very specialized applications. Hopefully through the use of this handbook, the experienced functional designer will be better able to evaluate an owner's requirements and to establish essential system criteria; the experienced mechanical designer will be better able to translate these criteria into effective system designs; and mechanical contractors will be provided with the knowledge needed to effectively carry out the intent of these designs to provide safe, reliable systems at reasonable cost. The previous issue of the handbook[20] has provided background information for a growing family of national standards covering air and gas cleaning systems for nuclear applications; the new issue will hopefully assist designers and engineers in using and interpreting those standards. It is also hoped that the volume will provide a rationale for the engineer, the manager, and the designer to justify the more costly, but necessary, features that a nuclear air cleaning system demands.

1.9 GLOSSARY

1.9.1 Dictionary of Acronyms and Initialisms

ACGIH American Conference of Governmental Industrial Hygienists

ACI American Concrete Institute

AEC Atomic Energy Commission (see ERDA, NRC)

AFI Air Filter Institute

AgX Silver-exchanged zeolite

ALAP As low as practicable (obsolete term for ALARA)

AISC American Institute of Steel Construction

ALARA As low as reasonably achievable

AMCA Air Moving and Conditioning Association

AMD Aerodynamic mean diameter (of particles)

ANSI American National Standards Institute

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers

ASME American Society of Mechanical Engineers

ASTM American Society for Testing and Materials

AWS American Welding Society

BET Brunauer, Emmett, and Teller (test for surface area of adsorbents)

BWR Boiling water reactor

CBR Chemical biological radiological (filter)

CFD Continuous fire detector

CH_3I Methyl iodide

CFR Code of Federal Regulations

CG Concentration guide

CRSI Concrete Reinforced Steel Institute

CWS Chemical Warfare Service

DBA Design basis accident

DBS Deep-bed sand (filter)

DBGF Deep-bed glass fiber (filter)

DF Decontamination factor

DOP Dioctyl phthalate

ERDA Energy Research and Development Administration

ES Equipment specification

ESF Engineered safety feature (system)

FRP Fiber-reinforced plastic

GMA Gas metal arc (welding)

GTA Gas tungsten arc (welding)

HEP Hazard equivalent plutonium

HEPA High-efficiency particulate air (filter)

HF Hydrogen fluoride

HTGR High-temperature gas-cooled reactor

HVAC Heating, ventilating, and air conditioning

HWESF Hanford Waste Encapsulation and Storage Facility

IAEA International Atomic Energy Agency

IES Institute of Environmental Sciences

KI Potassium iodide

Kr Krypton

LOCA Loss-of-coolant accident

LMFBR Liquid-metal fast breeder reactor

LWR Light water reactor

MMD Mass median diameter (of particles)

MPC Maximum permissible concentration

MPL_d Maximum permissible loading, desorption

MPL_i Maximum permissible loading, ignition

NBS	National Bureau of Standards
NFPA	National Fire Protection Association
NMD	Number mean diameter (of particles)
NRC	Nuclear Regulatory Commission
NRL	Naval Research Laboratory
NSIC	Nuclear Safety Information Center
OBE	Operating basis earthquake
ORNL	Oak Ridge National Laboratory
PL	Permissible leakage
PSU	Permanent single unit (adsorber)
PVA	Polyvinyl acetate
PWR	Pressurized water reactor
QA	Quality assurance
QAS	Quality assurance station
RG	Regulatory Guide
RH	Relative humidity
RSIC	Reactor Shielding Information Center
RTV	Room temperature vulcanizing (sealant or caulking compound)
SAR	Safety analysis report
SGTS	Standby gas treatment system
SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SRL	Savannah River Laboratory
SSE	Safe shutdown earthquake
TEDA	Triethylene diamine
TFE	Tetrafluoroethylene (plastic)
TLV	Threshold limit value
TURF	Thorium-Uranium Recycle Facility
UL	Underwriters' Laboratories
Xe	Xenon

1.9.2 Units of Measure and Metric Equivalents Used in This Handbook

cfm	cubic feet per minute	× 0.000472	= m^3/sec	cubic meters per second
fpm	feet per minute	× 0.00508	= m/sec	meters per second
ft	feet	× 0.3048	= m	meters
g	grams			
gal	gallons	× 3.78532	= liters	liters
gpm	gallons per minute	× 0.06309	= liters/sec	liters per second
gr	grains	× 0.0648	= g	grams
gr/ft^3	grains per cubic foot	× 2.288	= g/m^3	grams per cubic meter
hr	hours			
Hz	Hertz			
in.	inches	× 2.54	= cm	centimeters
in.wg	inches water gage	× 0.24836	= kPa	kilopascals
in.^{3}	cubic inches	× 0.01639	= liters	liters
lb	pounds	× 0.4536	= kg	kilograms
m	meter			
μm	micrometer			
mCi	millicuries			
μCi	microcuries			
min	minutes			
mR	milliroentgen			
millirem	milliroentgen equivalent man			
millirad	millirad			
ppm	parts per million			
psf	pounds per square foot	× 4.883	= kg/m^3	kilograms per cubic meter
psi	pounds per square inch	× 57.820	= g/cm^2	grams per square centimeter
rad	(unit of) radiation			
rem	roentgen equivalent man			
scfm	standard cubic feet per minute (see cfm)			
sec	seconds			
tonne	1000 kilograms			

1.9.3 Terms and Phrases

absolute filter. Obsolete term for HEPA filter.

acceptance test. A test made upon completion of fabrication, installation, repair, or modification of a system, unit, component or part to verify to the user or owner that the item meets specified requirements.

activation analysis. A method for identifying and quantitatively measuring chemical elements in a sample. Atoms in the sample are first made radioactive by bombardment with neutrons, charged particles, or other nuclear radiation; they then give off characteristic nuclear radiation by which they can be identified and their relative abundance can be determined.

adsorber. A device for removing gases or vapors from air by means of preferential physical condensation and retention of molecules on a solid surface. Adsorbers used in nuclear applications are often impregnated with chemicals to increase their activity for organic radioactive iodine compounds.

adsorber cell. A modular replaceable adsorber element.

AEC filter. A HEPA filter with fiberglass medium. Obsolete term for HEPA filter.

aerosol. A dispersion of very small particles and/or droplets in air.

air cleanup system. A system provided to decontaminate the air in, or exhausted from, a contained space following a system upset or prior to personnel access to the contained space.

air-generated DOP. See DOP.

ALAP. As low as practicable. Obsolete term for ALARA.

ALARA. As low as reasonably achievable. The design philosophy used to determine the need for, or extent of, air cleaning and off-gas facilities, based on their cost effectiveness in reducing adverse impacts with respect to offsite and onsite dose criteria. Formerly known as ALAP.

bag in, bag out. A method of introducing and removing items from a contaminated enclosure that prevents the spread of contamination or opening of the contaminated space to the atmosphere through the use of plastic bagging material.

case, casing. The frame or cell sides of a modular filter element.

clean-air device. A clean bench, clean work station, downflow module, or other equipment designed to control air cleanness (particle count) in a localized working area and incorporating, as a minimum, a HEPA filter and a fan.

clean-air system. An air cleaning system designed to maintain a defined level of air cleanness, usually in terms of a permissible number of particles in a given size range, within an enclosed working area.

clean room. An occupied room designed to maintain a defined level of air cleanness under operating conditions. Inlet air is cleaned by HEPA filters.

coating. Paint or other protective surface treatment applied by brushing, spraying, or dipping (does not include metallic plates).

contained space (contained volume). A building, building space, room, cell, glove box, or other enclosed volume in which air supply and exhaust are controlled.

containment (containment vessel or building). A gastight enclosure around a nuclear reactor or other nuclear facility designed to prevent fission products from escaping to the atmosphere.

contaminated exhaust system. An air cleaning system that is designed to remove harmful or potentially harmful particulates, mists, or gases from the air exhausted from contained space.

contamination. Any unwanted material in the air, in process fluids, or on surfaces. For the purposes of this handbook, contamination is usually assumed to be radioactive.

contamination zone. An isolable area which is, or which could become, contaminated and which is designed to facilitate decontamination.

controlled area. An area to which access is restricted.

cover gas. An inert gas, under pressure, provided in a contained space or process equipment item to prevent inleakage of air.

criticality. The state of sustaining a chain reaction, as in a nuclear reactor. When fissionable materials are handled or processed, they must be kept in a subcritical geometry, configuration, or mass to avoid accidental criticality.

critical system, unit, or item. One that is essential for adequate or safe operation, failure of which would cause loss of function.

CWS filter. Chemical Warfare Service filter—a term used for a HEPA filter with cellulose-asbestos medium, kraft paper separators, and untreated plywood casing. Obsolete term for HEPA filter.

decay heat. The heat produced by radioactive materials as nuclides spontaneously transform into other nuclides or into different energy states. Each decay process has a definite half-life.

decontamination. The removal of unwanted substances from personnel, rooms, building surfaces, equipment, etc.

decontamination factor. A measure of air cleaning effectiveness; the ratio of the concentration of a contaminant in the untreated air or gas to the concentration in the treated air or gas.

demister. The preferred generic term for devices used to remove entrained moisture from air (see *Thesaurus of Engineering and Scientific Terms*). Also a trademark of Otto H. York Company.

design basis accident (DBA). The most serious accident that can be hypothesized from an adverse combination of equipment malfunction, operating errors, and other unforeseen causes.

design pressure. The pressure that is used for the structural design of a unit, component, or system, and which includes allowance for forces encountered under system upset conditions.

double filtration. An arrangement of two filters in series with the second providing backup protection against leakage or failure of the first. Also a series arrangement intended to increase the total filtration efficiency.

DOP aerosol. A dispersion of dioctyl phthalate (DOP) droplets in air. Monodisperse DOP is generated by controlled vaporization and condensation of liquid dioctyl phthalate to give a cloud of droplets with diameters of approximately 0.3 μm. Polydisperse DOP is generated by blowing compressed air through liquid dioctyl phthalate and exhausting through special nozzles under controlled conditions to produce a cloud of droplets with a light-scattering mean diameter of approximately 0.7 μm.

dose. The amount of ionizing radiation energy absorbed per unit mass of irradiated material at a specific location. In the human body it is measured in rems; in inanimate bodies it is measured in rads.

double containment. An arrangement of double barriers in which the second barrier provides backup protection against leakage through or failure of the first.

dry-type filter. A filter having a medium that is not coated with an oil or adhesive to improve its retention of large particles.

enclosed filter. A filter that is completely enclosed on all sides and both faces except for reduced end connections or nipples for direct connection into a duct system. Enclosed filters are installed individually because there is a separate run of duct to each filter unit.

engineered safety feature (ESF). A unit or system that is provided to directly mitigate the consequences of a DBA.

extended-medium filter. A filter having a pleated medium or a medium in the form of bags, socks, or other shape to increase the surface area relative to the frontal area of the filter.

face guard. A screen, usually made from 4-mesh galvanized hardware cloth, permanently affixed to the face of a filter unit to protect it against damage caused by mishandling.

face shield. A screen or protective grille placed over a filter unit after it is installed to protect it from damage that might be caused from operations carried on in the vicinity of the filter.

fail safe. A design to give equipment the capability to fail without producing an unsafe condition.

filter. A device having a porous or fibrous medium for removing suspended particles from air or gas that is passed through the medium.

filter bank. A parallel arrangement of filters on a common mounting frame enclosed within a single housing.

final filter. The last filter unit in a set of filters arranged in series.

functional design. The establishment of airflow rates, airflow capacities, types of components to be employed, general system layout, operational objectives and criteria, decontamination factors and rates, space allocations, and other overall features of a system.

gas chromatograph. An analytical instrument used for quantitative analysis of extremely small quantities of organic compounds whose operation is based upon the absorption and partitioning of a gaseous phase within a column of granular material.

gas residence time. The calculated time that a contaminant or test agent theoretically remains in contact with an adsorbent, based on active volume of adsorbent and air or gas velocity through the adsorber bed.

glove box. A sealed enclosure in which all handling of items inside the box is carried out through long rubber or neoprene gloves sealed to ports in the walls of the enclosure. The operator places his hands and forearms in the gloves from the room side of the box so that he is physically separated from the glove box environment but is able to manipulate items inside the box with relative freedom while viewing the operation through a window.

HEPA filter. High-efficiency particulate air filter—also obsoletely known as AEC, CWS, superinterception, absolute, and superhigh-efficiency filter. A throwaway extended-pleated-medium dry-type filter with (1) a rigid casing enclosing the full depth of the pleats, (2) a minimum particle removal efficiency of 99.97% for thermally generated monodisperse DOP smoke particles with a diameter of 0.3 μm, and (3) a maximum pressure drop of 1.0 in.wg when clean and operated at its rated airflow capacity.

hot. Highly radioactive.

hot cell. A heavily shielded enclosure in which radioactive materials can be handled remotely with manipulators and viewed through shielding windows to limit danger to operating personnel.

in-box. Refers to an item within a glove box that can be handled or manipulated only by means of the box gloves or tools within the box.

in-cell. Refers to an item located within a cell or enclosure that can be handled or manipulated only by means of manipulators and/or a crane and other tools within the cell.

in-duct filter. Refers to a single-filter arrangement in which the filter unit is clamped between two sections of duct or taped into a space between two sections of duct.

in-place test. Penetration test of filter units or charcoal adsorbers made after they are installed.

inches of water. A unit of pressure or pressure differential (1 in.wg = 0.036 psi).

ionizing radiation. Any radiation (alpha, beta, or gamma) that directly or indirectly displaces electrons from the outer domains of atoms.

isotope. One of several forms or nuclides of the same chemical element that have the same number of protons in the nucleus and therefore have the same chemical properties, but have differing numbers of neutrons and differing nuclear properties.

kidney system. An air cleaning system that recirculates the air of a contained space.

leaktightness. The condition of a system, unit, or component where leakage through its pressure boundary is less than a specified maximum value at a specified pressure differential across the pressure boundary.

maximum permissible dose. The dose of ionizing radiation which competent authorities have established as the maximum that can be absorbed without risk to human health.

mechanical design. Detailed design of a system which results in exact layouts, equipment specifications, shop drawings, installation details and drawings, sizing and layout of ducts, housings and equipment, and other details necessary to achieve the objectives and meet criteria established in functional design.

medium (plural, media). The filtering material in a filter.

mounting frame. The structure to which a filter unit is clamped and sealed.

normal off-gas. The normal gaseous discharge from a process or process equipment item.

nuclear reactor. An apparatus in which a chain reaction of fissionable material is initiated and controlled.

off-gas. The gaseous effluent from a process or operation.

off-line system. One that is not operating or is normally held in standby.

on-line system. One that is operating or is normally in operation, as opposed to an off-line system.

open-face filter. A filter with no restrictions over the ends or faces of the unit, as opposed to the enclosed filter with reduced-size end connections.

operating pressure. The desired pressure corresponding to any single condition of operation.

overpressure. Pressure in excess of the design or operating pressure.

particle, particulate. A minute piece of solid matter having measurable dimensions. Also a radioactive particle (alpha, beta) which can liberate ionizing radiation or (neutron) which can initiate a nuclear transformation.

penetration. The measure of the quantity of a test agent that leaks through or around an air cleaning device when the device is tested with an agent of known characteristics under specified conditions; penetration is expressed as a percentage of the concentration of the test agent in the space upstream of the air cleaning device.

poison. Any material that tends to decrease the effectiveness of an adsorbent by occupying adsorption sites on the surface of the adsorbent or by reacting with the impregnants in the adsorbent.

prefilter. A filter unit installed ahead of another filter unit to protect the second unit from high dust concentrations or other environmental conditions. The prefilter usually has a lower efficiency for the finest particles present in the aerosol than the filter it protects (see **roughing filter**).

production test. A test made on each item or a sample of items or product from a production run to verify that the item meets specification requirements.

PSU adsorber. An adsorber that is permanently installed in a system and that can be emptied of and refilled with adsorbent without removing it from the system.

qualification test. A test made on a product or equipment item when it is proposed as a candidate to meet certain service requirements, which will verify to the user or owner that the item can meet his requirements (see **production test**).

rad. Radiation absorbed dose, the basic unit of ionizing radiation. One rad is equal to the absorption of 100 ergs of radiation energy per gram of matter.

radiation. The propagation of energy through matter or space in the form of electromagnetic waves or fast-moving particles (alpha and beta particles, neutrons, etc.). Gamma rays are electromagnetic radiation in which the energy is propagated in "packets" called photons.

radioactivity. The spontaneous decay or disintegration of an unstable atomic nucleus accompanied by the emission of radiation.

redundant unit or system. An additional and independent unit or system which is capable of achieving the objectives of the basic system and is brought on-line in the event of failure of the basic system.

rem. Roentgen equivalent man. The unit of absorbed radiation dose in rads multiplied by the relative biological effectiveness of the radiation.

roughing filter. A prefilter with high efficiency for large particles and fibers but low efficiency for small particles; usually of the panel type.

scrubber. A device in which the gas stream is brought into contact with a liquid so that undesirable components in the gas stream are removed by reacting with or dissolving in the liquid.

separators. Corrugated paper or foil (usually aluminum alloy or plastic) used to separate the folds of a pleated filter medium and to provide air channels between them.

service environment. The aggregate of conditions (temperature, pressure, humidity, radioactivity, chemical contaminants, etc.) that surround or flow through a system, unit, or component while serving the conditions of design.

shielding. A mass of absorbing material placed around a radioactive source to reduce ionizing radiation to levels not hazardous to personnel.

shock overpressure. The pressure intensity over and above atmospheric or operating pressure produced by a shock wave from an explosion, a suddenly closed damper, or other event.

specific radioactivity. Radioactivity per unit weight of a material.

spill. Accidental release of radioactive or other contaminating materials.

split system. A filter system consisting of two or more trains operating in parallel; one or more of the trains may be on standby.

standby system. One held in reserve.

surveillance test. A test made periodically to establish the current condition of a system, unit, component, or part.

system upset. An accident, system malfunction, or transient condition.

test program. A formalized schedule of tests which specifies the sequence of tests, the procedures to be employed, and the acceptance criteria.

train. A set of components arranged in series. In a filter system this may be as simple as a damper, HEPA filter, fan, and damper or as complex as a damper, condenser, moisture separator, heater, prefilter, HEPA filter, charcoal adsorber, another charcoal adsorber, HEPA filter, fan, and damper.

treatment. The process of removing all or a part of one or more chemical components, particulate components, or radionuclides from an off-gas stream.

REFERENCES FOR CHAP. 1

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4. Regulatory Guide 3.12, *General Design Guide for Ventilation Systems of Plutonium Processing and Fuel Fabrication Plants*, U.S. Atomic Energy Commission, Washington, D.C., 1973.

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7. *Industrial Ventilation*, American Conference of Governmental Industrial Hygienists, 13th ed., Lansing, Mich., 1974.

8. *ASHRAE Handbook—Systems, ASHRAE Handbook—Applications*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, New York.

9. ANSI Z9.2, *The Design and Operation of Local Exhaust Systems*, American National Standards Institute, New York, 1971.

10. P. A. F. White and S. E. Smith, eds., *High Efficiency Air Filtration*, Butterworth and Co., London and Washington, D.C., 1964.

11. C. N. Davies, *Air Filtration*, Academic Press, London and New York, 1973.

12. *TLVs—Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment*, American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio (issued annually).

13. Number decontamination factor, DF, is the ratio of the number concentration of particles in the unfiltered air to the number concentration in the filtered air. Where no subscript is appended, decontamination factor in this handbook means number decontamination factor, as opposed to decontamination factor based on mass of particulate (DF_m), intensity of radioactivity (DF_r), or volume concentration (DF_v).

14. E. J. Bauer et al., "The Use of Particle Counts For Filter Evaluation," *ASHRAE Journal*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, October 1973, pp. 53–59.

15. IES CS-1, *Standard for HEPA Filters*, Institute of Environmental Sciences, Mt. Prospect, Ill., current issue. (Formerly American Association for Contamination Control.)

16. The efficiency of a HEPA filter is based on its absolute particulate collection effectiveness; that is, the efficiency is relative to the number of particles present (see Sect. 3.2). The efficiency of common air filters, on the other hand, is based on the mass concentration of particulate matter (see Table 2.4) or on the staining effect of particulates on a reference surface, which is, of course, very subjective.

17. "Hazardous Solvent Use Causes Explosion In Glove Box" in *Serious Accidents*, U.S. Atomic Energy Commission, Issue No. 261, Feb. 25, 1966.

18. M. W. First and L. Silverman, "Cost and Effectiveness of Air-Cleaning Systems," *Nucl. Saf.* 4(1), 61–66 (September 1962).

19. This cost includes $120 for the new filter, $150 or more for handling and testing, and as much as $240 per filter for disposal and retrievable storage.

20. C. A. Burchsted and A. B. Fuller, *Design, Construction, and Testing of High-Efficiency Air Filtration Systems for Nuclear Application*, USAEC Report ORNL/NSIC-65, Oak Ridge National Laboratory, January 1970.